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Normative blood pressure response to exercise stress testing in children and adolescents

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ABSTRACT

Objective To describe normative values for blood pressure (BP) response to maximal exercise in children/adolescents undergoing a treadmill stress test.

Methods From a retrospective analysis of medical records, patients who had undergone a Bruce protocol exercise stress test, with (1) normal cardiovascular system and (2) a body mass index percentile rank below 95% were included for analysis. Sex, age, height, weight, resting and peak heart rate, resting and peak systolic blood pressure (SBP), test duration, stage of Bruce protocol at termination, reason for undergoing the test and reason for termination of test were collected. Percentiles for exercise-induced changes in SBP were constructed by age and height for each sex with the use of quantile regression models.

Results 648 patients with a median age of 12.4 years (range 6–18 years) were included. Typical indications for stress testing were investigation of potential rhythm abnormalities, syncope/dizziness and chest pain and were deemed healthy by an overseeing cardiologist. Mean test duration was 12.6±2.2 min. Reference percentiles for change in SBP by sex, age and height are presented.

Conclusion The presented reference percentiles for the change in SBP for normal children and adolescents will have utility for detecting abnormally high or low BP responses to exercise in these age groups.

Key questions

What is already known about this subject?

- There are established normative values for treadmill exercise for adults. In children, normative blood pressure responses to treadmill exercise have not been established.

What does this study add?

- This study provides normative values and percentiles for systolic blood pressure (SBP) responses for treadmill exercise for male and female children and adolescents aged 6–18 years old.

How might this impact on clinical practice?

- This study provides percentile tables for exercising SBP which can be used by clinicians in monitoring children and adolescents undergoing a Bruce protocol treadmill test.

INTRODUCTION

Paediatric exercise testing is used in the clinical assessment of possible arrhythmias, dyspnoea, ischaemia and cardiac dysfunction,[1] with blood pressure (BP) being a routine measure of the physiological response. While a moderate increase in BP with exercise is expected in children, normative values for treadmill exercise are not available. In adults, the normal BP response to exercise is well established[2 3] with a systolic value of ≥220 mm Hg considered an abnormally high exercise BP.[4–6] Conversely, there is currently no definition of an excessive BP response to treadmill exercise for the paediatric population.

Although the diagnostic significance of adult BP at rest and BP change with exercise are based on absolute cut-off values, resting paediatric BP values are typically classified by percentiles due to changes in normative values with growth and age.[7 8] For example, a 10-year-old male standing at 135 cm would be considered hypertensive with a resting systolic blood pressure (SBP) of 114 mm Hg, whereas a 20-year-old male would be considered hypertensive with a resting SBP of 130 mm Hg.[7] Therefore, the use of adult exercise cut-off values is likely to cause underdetection of excessive exercise BP responses in children. Under resting conditions, elevated BP is defined as ≥90th percentile, and hypertension is defined as BP of ≥95th percentile in children for their age, height and sex, with absolute cut-offs introduced at the age of 13 or 16 years of age (American and European guidelines, respectively).[7 8] Accordingly, we suggest that an excessive BP response to treadmill exercise in the paediatric population should also be presented as percentiles, with the 90th percentile defining elevated BP response and the 95th percentiles defining a hypertensive response.

Reference values for maximal treadmill exercise in normal healthy children are needed, noting that this form of stress test is the most commonly used in clinical settings. Thus far, the literature reporting normative paediatric cardiovascular response to exercise is predominately limited to cycle ergometer tests.[9 10] To the best of our knowledge, BP percentiles for treadmill tests are limited, with the exception of submaximal stimuli[2] and athletes,[11] or they do not take into account height percentiles.[12]

The aim of this study was therefore to define normative reference values for maximal exercise BP response in children and adolescents for the standard Bruce treadmill stress test.

METHODS

Data were collected retrospectively. It was not possible to involve patients or the public in the design, conduct, reporting or dissemination plans of our research study.

Data were collected from pre-existing stress test results from patients who had undergone a routine standard Bruce protocol exercise stress test from 1990 to 2018 at Royal Children's Hospital. Typical indications for testing included chest pain, palpitations, dizziness and syncope but were considered normal after assessment by a qualified cardiologist. All tests were supervised by a cardiac technologist and medical staff.

Exercise stress test

After patient preparation and application of ECG electrodes in the supine position, an appropriately sized BP cuff was placed over the right upper arm. The patient lay in the supine position for approximately 10 min prior to a single resting auscultatory BP measurement.[1] The cuff was inflated to approximately 20 mm Hg above SBP, after which the pressure was slowly released from the cuff. Resting SBP and diastolic blood pressure (DBP) were recorded via the auscultatory method using a calibrated aneroid manometer. The patient was then moved to the treadmill where the Bruce protocol was used, beginning at an incline grade of 10% and speed of 2.74 km/hour and increasing by 2% at 3 min intervals. The speed also increased with each change in inclination, until the patient reached volitional fatigue or completed the seventh and final stage (22% grade and 9.65 km/hour). On completion of the test, the patient immediately returned to the supine position, where peak BP was measured. The reason for termination of exercise was recorded. Data were recorded and entered into an electronic database.

Data analysis

Patient records were assessed to ensure that they completed a standard Bruce protocol exercise stress test and that they had structurally and functionally normal cardiovascular systems. Additionally, the patient's body mass index (BMI) was compared against Centers for Disease Control and Prevention (CDC, Washington, DC, USA) BMI-for-age charts. Subjects with a BMI of >95th percentile for their sex and age and subjects whose underlying symptomatology may have influenced BP response (ie, coarctation of the aorta) were excluded. Subjects with a resting BP reading that was considered hypertensive, ≥95th percentile based on age, sex and height, as defined by Flynn *et al*,[7] were excluded. Where multiple exercise tests were performed by a particular patient, results from the first test were used. As an indicator of adequate effort, only data where the children had reached 85% of their age-predicted heart rate and were in a normal heart rhythm were included. The following variables were recorded: sex, age, height, weight, resting SBP, resting heart rate, peak SBP, peak heart rate, duration of test, stage of Bruce protocol, recorded reason for terminating the test and indication for the stress test. For the purpose of this study, we have only provided SBP reference values since measurement of DBP with exercise is unreliable in children.[13–19]

Statistical analysis

Sample size justification

At rest, a BP above the 95th percentile defines hypertension in children (up to the age of 13 or 16 years).[7 8] In

Table 1 Patient characteristics

Variable	Total (N=648)	Female (n=334)	Male (n=314)
Age (years)	12.4 (9.7–14.8)	12.9 (10–15)	12.2 (9.6–14.7)
Weight percentile	61.9 (38.2–81.7)	63.4 (42.4–82.2)	61.1 (36.6–81.7)
Height percentile	65.1 (38.1–84.1)	65.4 (38.3–82.8)	64.8 (37.6–84.6)
BMI percentile	58.4 (31.6–77.2)	62.2 (37–80.2)*	55.2 (27.2–75.1)
BMI category			
Healthy	619 (82%)	307 (82%)	312 (83%)
Overweight	107 (14%)	57 (15%)	50 (13%)
Underweight	27 (4%)	12 (3%)	15 (4%)

Data presented as median (IQR).
*P< 0.001 compared with males.
BMI, body mass index.

this study, we defined percentiles in children and adolescents up to age 18 years. Using regression-based reference limits, a 95% reference range (defining exercise hypertension), 90% CI, 10% relative margin of error for the reference range and assuming a uniform distribution of ages, we found that a sample size of 377 was required (calculated via MedCalc software).

Statistical methods

Analyses were performed in Stata V.16 and R software V.4.0.1. Patient characteristics are presented for the whole sample and by sex. As per the reference ranges provided by Flynn *et al*,[7] we constructed age, sex and height percentile-specific reference ranges using quantile regression to estimate the 5th, 10th, 50th, 90th and 95th percentile reference curves for the change in SBP, measured as the difference between SBP at rest and at peak exercise.

RESULTS

A total of 756 medical records were assessed (50% male). Of these, 42 were excluded due to BMI of >95th percentile, and 66 were excluded due to failure to reach sufficient exercise intensity of ≥85% of age-predicted maximum heart rate. This left 334 records for females, and 314 records for males. The median age was 13 years for females and 12 years for males (table 1). Most patients (~80%, for both males and females) had a healthy BMI (58th percentile) (table 1), with females having a higher BMI (62nd percentile) than males (55th percentile) (p<0.001).

The average test duration was 12.6±2.2 min, with males having a longer average test duration compared with females (p<0.001). The average increase in SBP from rest to peak exercise was 43±15 mm Hg and did not differ between males and females (p=0.2) (table 2). The average resting heart rate was 83±16 beats/min and increased to 195±9 beats/min at peak exertion (table 2).

Percentiles for female and male SBP changes in response to exercise are provided in tables 3 and 4,

Table 2 Stress test summary

Variable	Total (N=648)	Female (n=334)	Male (n=314)
Resting SBP (mm Hg)	101.2 (10.0)	101.1 (10.3)	101.4 (9.8)
Resting SBP percentile	38.5 (26.6)	38.0 (27.1)	35.1 (23.5)
Peak SBP (mm Hg)	144.3 (18.2)	143.5 (16.7)	145.2 (19.6)
Change in SBP (mm Hg)	43.1 (14.6)	42.4 (13.9)	43.8 (15.3)
Resting DBP (mm Hg)	58.9 (7.6)	59.2 (7.9)	58.7 (7.3)
Resting DBP percentile	39.7 (23.6)	38.3 (23.3)	37.9 (20.1)
Resting HR (beats/min)	83.1 (15.6)	84.2 (15.5)	81.9 (15.5)
Peak HR (beats/min)	195.0 (9.4)	195.2 (9.0)	194.7 (9.7)
Percentage of predicted maximum HR	93.9 (4.7)	94.1 (4.6)	93.7 (4.9)
Test duration	12.6 (2.2)	12.0 (1.9)	13.3 (2.4)*
Stage of Bruce protocol reached			
2	1 (0%)	0 (0%)	1 (0%)
3	16 (2%)	11 (3%)	5 (2%)
4	228 (35%)	149 (45%)	79 (25%)
5	303 (47%)	150 (45%)	153 (49%)
6	90 (14%)	22 (7%)	68 (22%)
7	10 (2%)	2 (1%)	8 (3%)
Reason for termination			
Adequate or complete time reached	9 (1%)	3 (1%)	6 (2%)
Chest pain/dizziness/collapse	54 (8%)	42 (13%)	12 (4%)
Fatigue/shortness of breath/sore body (chest)/anxiety/distress/poor treadmill coordination	575 (89%)	282 (84%)	293 (93%)
Other	4 (1%)	1 (0%)	3 (1%)
Sudden collapse	2 (0%)	2 (1%)	0 (0%)
Unknown	4 (1%)	4 (1%)	0 (0%)

Data presented as mean (SD) or N (%).
*P< 0.001 compared with females.
DBP, diastolic blood pressure; HR, heart rate; SBP, systolic blood pressure.

Table 3 Percentiles for female SBP response to exercise (ie, change from baseline pressure) by age and height (n=334)

Height percentile								
Change in SBP percentile								
Age	**Unit**	**P5**	**P10**	**P25**	**P50**	**P75**	**P90**	**P95**
6	cm	106.9	108.6	111.6	115	118.6	121.9	123.9
	in	42.1	42.8	43.9	45.3	46.7	48	48.8
	5th	16	17	18	20	21	22	23
	10th	18	18	19	20	21	21	22
	50th	33	34	35	36	37	38	39
	90th	38	39	42	44	47	49	50
	95th	42	43	44	46	48	49	50
7	cm	113.1	114.9	118.1	121.8	125.6	129.1	131.3
	in	44.5	45.2	46.5	47.9	49.4	50.8	51.7
	5th	16	17	18	20	21	23	23
	10th	19	19	20	21	22	22	23
	50th	34	35	36	37	38	39	39
	90th	40	42	44	46	49	51	53
	95th	44	45	47	49	50	52	53
8	cm	118.5	120.5	123.9	127.8	131.9	135.6	137.9
	in	46.7	47.5	48.8	50.3	51.9	53.4	54.3
	5th	17	17	19	20	21	23	23
	10th	20	20	21	22	22	23	24
	50th	35	36	37	38	39	40	40
	90th	42	44	46	49	51	53	55
	95th	47	48	49	51	53	54	55
9	cm	123.2	125.3	129	133.1	137.4	141.4	143.8
	in	48.5	49.3	50.8	52.4	54.1	55.7	56.6
	5th	17	17	19	20	21	23	23
	10th	21	21	22	23	23	24	24
	50th	36	37	38	39	40	41	41
	90th	44	46	48	51	53	56	57
	95th	50	50	52	54	55	57	58
10	cm	127.5	129.8	133.7	138.2	142.8	147	149.6
	in	50.2	51.1	52.6	54.4	56.2	57.9	58.9
	5th	17	17	19	20	22	23	24
	10th	22	22	23	23	24	25	25
	50th	37	37	38	39	41	42	42
	90th	47	48	50	53	55	58	59
	95th	52	53	55	56	58	60	60
11	cm	132.4	135	139.4	144.3	149.2	153.7	156.4
	in	52.1	53.1	54.9	56.8	58.7	60.5	61.6
	5th	17	18	19	20	22	23	24
	10th	22	23	24	24	25	26	26
	50th	38	38	39	40	41	42	43
	90th	49	50	52	55	58	60	61
	95th	55	56	57	59	61	62	63
12	cm	139.2	142	146.5	151.5	156.4	160.8	163.5
	in	54.8	55.9	57.7	59.6	61.6	61.6	64.4
	5th	17	18	19	20	22	23	24
	10th	23	24	24	25	26	27	27
	50th	39	39	40	41	42	43	44
	90th	51	52	55	57	60	62	63
	95th	57	58	60	61	63	65	66
13	cm	145.9	148.4	152.7	157.3	162	166.1	168.6
	in	57.4	58.4	60.1	61.9	63.8	65.4	66.4
	5th	17	18	19	20	22	23	24
	10th	24	25	25	26	27	28	28
	50th	40	40	41	42	43	44	45
	90th	53	54	57	59	62	64	66
	95th	60	61	62	64	66	67	68
14	cm	149.7	152.1	156	160.5	164.9	168.9	171.3
	in	58.9	59.9	61.4	63.2	64.9	66.5	67.4
	5th	17	18	19	20	22	23	24
	10th	25	25	26	27	28	28	29
	50th	40	41	42	43	44	45	46
	90th	55	57	59	62	64	66	68
	95th	62	63	65	66	68	70	71
15	cm	151.3	153.6	157.5	161.9	166.3	170.2	172.6
	in	59.6	60.5	62	63.7	65.5	67	68
	5th	17	18	19	21	22	23	24
	10th	26	26	27	28	29	29	30
	50th	41	42	43	44	45	46	47
	90th	57	59	61	64	66	69	70
	95th	65	66	67	69	71	72	73
16	cm	151.9	154.3	158.2	162.6	166.9	170.9	173.2
	in	59.8	60.7	62.3	64	65.7	67.3	68.2
	5th	17	18	19	21	22	23	24
	10th	27	27	28	29	30	30	31
	50th	42	43	44	45	46	47	47
	90th	60	61	63	66	68	71	72
	95th	67	68	70	72	73	75	76
17	cm	152.3	154.6	158.6	162.9	167.3	171.2	173.6
	in	60	60.9	62.4	64.1	65.9	67.4	68.3
	5th	17	18	19	21	22	23	24
	10th	28	28	29	30	30	31	32
	50th	43	44	45	46	47	48	48
	90th	62	63	65	68	71	73	74
	95th	70	71	71	74	76	77	78
18	cm	152.5	154.8	158.8	163.1	167.5	171.4	173.8
	in	60	61	62.5	64.2	65.9	67.5	68.4
	5th	17	18	19	21	22	23	24
	10th	29	29	30	31	31	32	32
	50th	44	45	45	47	48	49	49
	90th	64	65	68	70	73	75	76
	95th	72	73	75	77	78	80	81

SBP, systolic blood pressure.

Table 4 Percentiles for male SBP response to exercise (ie, change from baseline pressure) by age and height (n=334)

Height percentile								
Change in SBP percentile								
Age	**Unit**	**P5**	**P10**	**P25**	**P50**	**P75**	**P90**	**P95**
6	cm	107.3	109.2	112.2	115.7	119.1	122.1	123.9
	in	42.2	43	44.2	45.5	46.9	48.1	48.8
	5th	11	11	12	12	13	14	14
	10th	16	16	17	18	19	19	20
	50th	28	29	30	31	32	32	33
	90th	36	37	38	40	42	44	45
	95th	41	43	45	47	50	52	53
7	cm	113.2	115.1	118.4	122	125.7	129	131
	in	44.6	45.3	46.6	48	49.5	50.8	51.6
	5th	12	12	13	14	14	15	16
	10th	17	17	18	19	20	21	21
	50th	30	31	32	33	34	34	35
	90th	39	40	42	44	45	47	48
	95th	44	46	48	50	53	55	56
8	cm	118.8	120.8	124.3	128.1	132.1	135.7	137.8
	in	46.8	47.6	48.9	50.4	52	53.4	54.3
	5th	13	14	14	15	16	16	17
	10th	18	19	19	20	21	22	22
	50th	32	33	34	35	36	36	37
	90th	42	43	45	47	49	51	52
	95th	47	49	51	53	56	58	59
9	cm	123.8	126	129.6	133.7	137.9	141.8	144.1
	in	48.7	49.6	51	52.7	54.3	55.8	56.7
	5th	15	15	16	16	17	18	18
	10th	19	20	21	21	22	23	24
	50th	34	35	36	37	38	39	39
	90th	46	47	48	50	52	54	55
	95th	50	52	54	56	59	61	62
10	cm	128.2	130.5	134.4	138.8	143.3	147.4	149.9
	in	50.5	51.4	52.9	54.7	56.4	58	59
	5th	16	16	17	18	18	19	19
	10th	21	21	22	23	24	24	25
	50th	36	37	38	39	40	41	41
	90th	49	50	52	54	56	57	58
	95th	53	55	57	59	62	64	65
11	cm	132.4	134.9	139	143.7	148.5	152.9	155.5
	in	52.1	53.1	54.7	56.6	58.5	60.2	61.2
	5th	17	18	18	19	20	20	21
	10th	22	22	23	24	25	26	26
	50th	38	39	40	41	42	43	43
	90th	53	54	55	57	59	61	62
	95th	56	58	60	62	62	67	68
12	cm	137.3	139.9	144.3	149.3	154.4	159	161.9
	in	54.1	55.1	56.8	58.8	60.8	62.6	63.7
	5th	18	19	19	20	21	22	22
	10th	23	23	24	25	26	27	27
	50th	40	41	42	43	44	45	45
	90th	56	57	59	61	62	64	65
	95th	59	61	63	65	68	70	71
13	cm	143.6	146.4	151.1	156.4	161.7	166.6	169.5
	in	56.5	57.6	59.5	61.6	63.7	65.6	66.7
	5th	20	20	21	22	22	23	23
	10th	24	25	25	26	27	28	29
	50th	43	43	44	45	46	47	47
	90th	59	60	62	64	66	68	69
	95th	62	64	66	68	71	73	74
14	cm	150.5	153.6	158.7	164.1	169.5	174.2	177
	in	59.3	60.5	62.5	64.6	66.7	68.6	69.7
	5th	21	21	22	23	24	24	25
	10th	25	26	27	28	29	29	30
	50th	45	45	46	47	48	49	49
	90th	63	64	65	67	69	71	72
	95th	66	67	69	71	74	76	77
15	cm	156.7	159.8	164.8	170.1	175.3	179.8	182.4
	in	61.7	62.9	64.9	67	69	70.8	71.8
	5th	22	23	23	24	25	26	26
	10th	27	27	28	29	30	31	31
	50th	47	47	48	49	50	51	51
	90th	66	67	69	71	73	74	75
	95th	69	70	72	74	77	79	80
16	cm	160.8	163.7	168.5	173.6	178.6	182.9	185.5
	in	63.3	64.5	66.3	68.4	70.3	72	73
	5th	24	24	25	25	26	27	27
	10th	28	28	29	30	31	32	32
	50th	49	49	50	51	52	53	53
	90th	69	71	72	74	76	78	79
	95th	72	73	75	77	80	82	83
17	cm	163.1	165.8	170.4	175.3	180.2	184.5	187
	in	64.2	65.3	67.1	69	70.9	72.6	73.6
	5th	25	25	26	27	27	28	28
	10th	29	30	30	31	32	33	33
	50th	51	51	52	53	54	55	55
	90th	73	74	76	78	79	81	82
	95th	75	76	78	81	83	85	86
18	cm	164.2	166.9	171.3	176.2	181	185.3	187.8
	in	64.7	65.7	67.5	69.4	71.3	72.9	73.9
	5th	26	27	27	28	29	29	30
	10th	30	31	32	33	33	34	35
	50th	53	53	54	55	56	57	57
	90th	76	77	79	81	83	85	86
	95th	78	79	81	84	86	88	89

Continued

Table 4 Continued

SBP, systolic blood pressure.

respectively. The changes in BP on exertion varied with age and height. Increases in SBP were higher in males than in females of the same age.

DISCUSSION

In adults, BP reference values are used to predict increased risk of morbidity and mortality, and there is evidence that exercise BP is superior for this purpose compared with resting BP.[20–25] However, normative values for BP response to treadmill exercise in children and adolescents have not been available to date. It is currently unknown whether or not elevated exercise BP in children has the same predictive risk valu as that of adults. However, longitudinal studies of resting BP have found high BP in childhood tracks into adulthood.[26] The normative values provided in this study will allow clinicians and researchers to identify those children with excessive increases in BP and follow them longitudinally and gain a better understanding of using exercise BP as a predictive risk assessment in the paediatric population. In addition, BP responses in conditions affecting the aortic arch such as repaired coarctation, transposition of the great arteries following arterial switch, Williams syndrome and many others can now be considered against normative data.

The majority of reference papers in the literature focus on cardiovascular response to cycle ergometers, and as such, reference values for treadmill testing are limited,[9 10] with the exception of submaximal stimuli[11] and athletes.[9] Sasaki *et al*[12] recently published percentiles for children undergoing exercise on treadmills; their findings were based on a modified Bruce protocol and did not account for height or resting BP in their percentiles.[12] Understanding BP response on a cycle ergometer is useful, especially as cycle ergometers are cheaper and quieter and require less space for exercise labs.[1] Additionally, cycle ergometers are better for individuals with weight-bearing limitations[27]; however, individuals tend to reach muscular fatigue before reaching volitional fatigue.[1] Conversely, volitional fatigue is reached first with treadmill exercise resulting in a maximal oxygen consumption approximately 10% greater than that of cycling.[1 28] Therefore, if the purpose of the stress test is to reach volitional fatigue, treadmill exercise will be more appropriate for diagnostic purposes and determination of functional capacity in children.[1] An additional benefit of treadmill exercise is that most individuals are familiar with the mechanics of walking from a very young age, whereas the biomechanics of cycling and maintaining cadence are not as familiar to all children.[1] Furthermore, since treadmills are the most common apparatus for exercise testing in children,[1] the reference values described herein will aid clinicians in determining normal and abnormal BP responses. Previously, a lack of current reference values meant diagnostic, prognostic and therapeutic decisions were currently based on subjective clinical experience. With this in mind, there is little consensus on what is appropriate for paediatric BP response to exercise, making clinical decisions difficult even with subjective experience. The data provided in this study can now be referenced to determine appropriate BP response and identify patients who may need further consultation in determining whether masked hypertension is present.

In young adults (20–29 years), the average change in SBP from rest to maximal exercise is 53±19 mm Hg for males and 46±17 mm Hg for females.[29] Our study indicated excellent continuity with these findings, given that older adolescents (aged 18 years) had an average SBP response (50th percentile) of 55 mm Hg for males and 47 mm Hg for females. In adults, a single absolute BP cut-off of 220 mm Hg has been suggested for defining exercise hypertension, although Schultz *et al*[30] noted that an exaggerated BP response is often expressed as a sex-dependent cut-off value at the 90th or 95th percentile (SBP; ~210 mm Hg for males and~190 mm Hg for females). For adolescents ≥13 years of age, single cut-off values have been used to define resting hypertensive status.[7] However, in children, the percentile approach is more appropriate than a single cut-off, given the physiological and stature changes that continue during development. The 95th percentile of BP changes in 18 year olds adults (males: 78–89 mm Hg, females; 72–81 mm Hg, females, immediately post-exercise in supine position) were relatively similar to the changes seen in 20–29 year-olds (88 for males and 70 mm Hg for females, measured during exercise stress test, calculated as difference between absolute 95th percentile and group average resting BP) indicating that the use of percentiles is more appropriate up to the age of 18 for exercise BP.[29]

In the current study, percentiles were presented for all ages (6–18 years). The European guidelines for management of arterial hypertension noted that while there are recommended cut-off values for exercise BP, a single value does not take into account variations in pre-exercise BP, age, sex, arterial stiffness and obesity status.[31] The normative values presented in this study took into account key individual characteristics, including age, sex, height and pre-exercise BP (by presenting change in SBP instead of peak exercise BP).

Study limitations and strengths

The age distribution was approximately bell-shaped and hence was not uniformly distributed; however, this reflects the typical ages that children present for this form of testing. Reflecting the ethnic mix of this area of Australia, participants were mostly Caucasian (European and Mediterranean) but included children of Asian and Middle Eastern descent as well as other ethnic groups. Therefore, these data may not be representative of other ethnicities or regions. Data were collected using standard auscultatory methods[1]; while some centres may prefer oscillometric devices, to the best of our knowledge, no oscillometric devices have been validated for exercise BP measurement in the paediatric population. Since data were collected over two decades, the personnel involved in supervising the test inevitably varied. All BP measurements were taken by a cardiologist with at least 5 years' experience and using standard techniques.

As with all forms of exercise testing to assess peak ability, these depend on the volition of the child to perform. The strength of this study was the inclusion criteria that subjects had to reach a heart rate of at least 85% of maximum age-predicted heart rate as an indicator of adequate effort. We excluded obese individuals from this study, as these subjects tend to have increased BP that could skew the change in BP from rest to exercise, thus altering normal percentiles.[7] Using these references values, it will now be possible to determine if children with obesity have an abnormal SBP response to exercise. Additionally, it will be possible to determine if other chronic pathological conditions, such as vascular and renal diseases, produce an exaggerated BP response with exercise.

CONCLUSION

We have described normative values of SBP response to maximal exercise (≥85% of age-predicted heart rate max) for a treadmill stress test in children and adolescents. These data will enable clearer identification of abnormal BP response and improve cardiovascular risk assessment in children.

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Contributors MMHC, JPM and JK conceptualised and designed the study, provided intellectual feedback, and reviewed and revised the manuscript. JPG and NPS designed the data collection instruments, assisted in data collection, and reviewed and revised the manuscript. SP-G assisted in data collection and reviewed and revised the manuscript. DZ provided statistical expertise in generating normative value percentiles and reviewed and revised the manuscript. MMC helped conceptualise and design the study, designed the data collection instruments, coordinated and supervised data collection, drafted the manuscript, and reviewed and revised the manuscript. All authors approved the final manuscript as submitted and agreed to be accountable for all aspects of the work.

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